AFRL-HE-BR-TR-2005-0071

United States Air Force Research Laboratory

A FATIGUE CHECKCARD FOR MISHAP INVESTIGATIONS

James C. Miller

HUMAN EFFECTIVENESS DIRECTORATE
BIOSCIENCES AND PROTECTION DIVISION
FATIGUE COUNTERMEASURES BRANCH
8248 CHENNAULT PATH
BROOKS CITY-BASE TX 78235-5105

May 2005

NOTICES

This report is published in the interest of scientific and technical information exchange and does not constitute approval or disapproval of its ideas or findings.

This report is published as received and has not been edited by the publication staff of the Air Force Research Laboratory.

Using Government drawings, specifications, or other data included in this document for any purpose other than Government-related procurement does not in any way obligate the US Government. The fact that the Government formulated or supplied the drawings, specifications, or other data, does not license the holder or any other person or corporation, or convey any rights or permission to manufacture, use, or sell any patented invention that may relate to them.

The Office of Public Affairs has reviewed this paper, and it is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

This report has been reviewed and is approved for publication.

//SIGNED//
JAMES C. MILLER, Ph.D.
Project Scientist

//SIGNED//
F. WESLEY BAUMGARDNER, Ph.D.
Deputy, Biosciences and Protection Division

REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
May 2005	Interim	1 Jul - 30 Sep 2004

4. TITLE AND SUBTITLE A FATIGUE CHECKCARD FOR MISHAP INVESTIGATIONS	**5a. CONTRACT NUMBER**
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) James C. Miller	**5d. PROJECT NUMBER** 7757
	5e. TASK NUMBER P9
	5f. WORK UNIT NUMBER 04
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Human Effectiveness Directorate Biosciences and Protection Division Fatigue Countermeasures Branch Brooks City-Base, TX 78235	**8. PERFORMING ORGANIZATION REPORT**
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Human Effectiveness Directorate Biosciences and Protection Division Fatigue Countermeasures Branch 8248 Chennault Path Brooks City-Base, TX 78235	**10. SPONSOR/MONITOR'S ACRONYM(S)** AFRL/HE **11. SPONSOR/MONITOR'S REPORT NUMBER(S)** AFRL-HE-BR-TR-2005-0071

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES

Investigators of workplace and transportation accidents and incidents seldom have the instruments or expertise required to determine whether or not human fatigue might have contributed to the mishap. The Fatigue Checkcard and its associated protocol were designed as a screening tool to fill this need. Briefly, using the Checkcard, the investigator may generate a score based upon seven simple observations: Length of prior wakefulness, amount of prior sleep for the preceding 72 hours, time of mishap, number of night shifts in preceding 30 days, time zone change and days in zone, types of human errors associated with mishap, and estimated physical exertion across the work period of interest. If the score is above a criterion level shown on the card, then the investigator should contact a fatigue expert for additional help with the investigation. The Fatigue Checkcard was designed in part using the U.S. Department of Defense Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) applied model, implemented as the *FAST*™ software. The SAFTE applied model integrated the effects of length of prior wakefulness, amount of sleep and circadian rhythm. This Fatigue Checkcard and its associated protocol were provided as the response to an Eagle Look recommendation made by the Inspector General of the Air Force and approved by the Air Staff.

15. SUBJECT TERMS
Accidents and Incidents; instruments; expertise; human fatigue; mishap; factor; Checkcard; protocol; score; prior wakefulness; prior sleep night shifts; time zone change; human error; physical exertion; Sleep; Activity; Fatigue; and Task Effectiveness; SAFTE; applied model; FAST software; Eagle Look; Inspector General

16. SECURITY CLASSIFICATION OF: UNCLASSIFIED			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** Dr. James C. Miller
a. REPORT UNCLASSIFIED	**b. ABSTRACT** UNCLASSIFIED	**c. THIS PAGE** UNCLASSIFIED	UNCLAS	29	**19b. TELEPHONE NUMBER** *(include area code)* 210-536-2742

THIS PAGE INTENTIONALLY LEFT BLANK

CONTENTS

FIGURES

PREFACE

This Technical Memorandum covers the project period of 1 July 2004 to 30 September 2004. The work was performed under Job Order Number 7767P904. The project manager was Dr. James C. Miller, Senior Research Physiologist, Fatigue Countermeasures Branch, Biosciences and Protection Division, Air Force Research Laboratory (AFRL/HEPF).

This Technical Memorandum was written in response to a recommendation made by the Inspector General of the Air Force and approved by the Air Staff. The recommendation was included in the final report of the AFIA Eagle Look PN 04-602, May 2004, "Shift Worker Fatigue." It was Recommendation 3-2, "Modify the AFRL fatigue assessment check card to include physical fatigue and shift lag. Build a fatigue assessment protocol into AFSAS in support of Recommendation 1-1. (OPRs: SAF/AQ [AFMC/AFRL], AF/SE)."

The author is indebted to Drs. Douglas R Eddy and William F. Storm of NTI, Inc., for their helpful editorial comments.

SUMMARY

Investigators of workplace and transportation accidents and incidents seldom have the instruments or expertise required to determine whether or not human fatigue might have contributed to the mishap. The Fatigue Checkcard and associated protocol were designed as a screening tool to fill this need. Briefly, using the Checkcard, the investigator may generate a score based upon seven simple observations: Length of prior wakefulness, amount of prior sleep for the preceding 72 hours, time of mishap, number of night shifts in preceding 30 days, time zone change and days in zone, types of human errors associated with mishap, and estimated physical exertion across the work period of interest. If the score is above a criterion level shown on the card, then the investigator should contact a fatigue expert for additional help with the investigation (i.e., to confirm or negate the positive result of the Checkcard screening).

The Fatigue Checkcard was designed in part using the U.S. Department of Defense Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) applied model, implemented as the Fatigue Avoidance Scheduling Tool (*FAST*™) software. The SAFTE applied model integrated the effects of length of prior wakefulness, amount of sleep and circadian rhythm.

This Fatigue Checkcard and its associated protocol were provided as the response to an Eagle Look recommendation made by the Inspector General of the Air Force and approved by the Air Staff.

A FATIGUE CHECKCARD FOR MISHAP INVESTIGATIONS

INTRODUCTION

Investigators of workplace and transportation accidents and incidents seldom have the instruments or expertise required to determine whether or not human fatigue (Appendix A) might have contributed to the mishap. The Fatigue Checkcard and associated protocol were designed as a screening tool to fill this need. Briefly, using the Checkcard, the investigator may generate a score based upon seven simple observations. If the score is above a criterion level shown on the card, then the investigator should contact a fatigue expert for additional help with the investigation (i.e., to confirm or negate the positive result of the Checkcard screening).

BACKGROUND

An initial version of this Checkcard was created in March 2003, based solely upon expert opinion and without systematic reference to a quantitative model (Appendix C). The original Checkcard included scores for five factors:

- Length of prior wakefulness (including most recent sleep loss, if any, and concomitant acute fatigue)
- Amount of prior sleep for the preceding 72 hours (h) (including next-most recent sleep loss, if any, and concomitant cumulative fatigue)
- Time of day/night of the mishap (circadian rhythm effects)
- Time zone crossings in the preceding 14 days (jet lag effects)
- Types of human errors associated with mishap

The modification of the Fatigue Checkcard described here was accomplished in response to a recommendation made by the Inspector General of the Air Force and approved by the Air Staff. The recommendation was included in the final report of the Air Force Inspection Agency's Eagle Look PN 04-602, "Shift Worker Fatigue." It was Recommendation 3-2, "Modify the AFRL fatigue assessment check card to include physical fatigue and shift lag. Build a fatigue assessment protocol into the AFSAS" (the Air Force Safety Automated System). The offices of primary responsibility were our Fatigue Countermeasures Branch within the Air Force Research Laboratory [via the office of the Assistant Secretary of the Air Force for Acquisition (SAF/AQ)] and the Air Force Safety Center (AF/SE).

This present version improves upon the former Checkcard by using expert opinion plus a quantitative approach to create some of the fatigue scores, and by adding two more fatigue factors. This improvement of the Checkcard included:

- Re-scaling some of the scores, above, based upon a quantitative prediction tool
- Adding a score for the effects of shift work
- Adding a score for physical fatigue

METHODS

The Fatigue Checkcard was designed in part using the U.S. Department of Defense Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) applied model (Hursh et al., 2004, and Appendix B). This applied model had been implemented in the Windows program, Fatigue Avoidance Scheduling Tool (*FAST*™, NTI Inc., Dayton OH, and Appendix B), which was used to make the calculations used and to draw the figures shown in this Memorandum. There were a number of other quantitative models of the effects of fatigue on human cognitive performance (Neri, 2004), but no other model provided quantitative estimates specialized for military operations.

The SAFTE applied model integrated the effects of length of prior wakefulness, amount of sleep and circadian rhythm (Appendix B). Thus, the scores created for these Checkcard factors were not independent scores. This lack of independence introduced a conservative bias in scoring with respect to safety. That is, the scores were biased slightly toward a preliminary finding of a fatigue effect. This was viewed as being an advantage for the effective use of the Checkcard in the field because an investigator is likely to acquire only part of the whole mishap picture from interviews.

Each of the items on the Checkcard was scaled on the dimension, likelihood of a fatigue effect, from 1 (little or no likelihood) to 5 (strong likelihood). An odd-numbered scale maximum was used to allow us to identify "moderate" likelihood in the middle of the scale. Five ordinal scale values were used because three ordinal levels provided too little resolution for two scaled items and we could not justify seven levels of resolution.

Although the items on the Checkcard are called "Factors," they were not selected through the statistical process known as factor analysis. They were selected on the basis of expert opinion.

The effects of age and sleep disorders were not considered here since they were viewed as lying outside the scope of Air Force investigative needs. The effects of alcohol intoxication may be considered additive with the effects of fatigue on attention and some kinds of cognitive performance. Sixteen to 17 hours of continuous wakefulness (a normal day) brings the average person to an approximate cognitive equivalency with a 0.05% blood alcohol content (Dawson and Reid, 1997), while 20 hours of continuous wakefulness brings the average person to an approximate cognitive equivalency with a 0.10% blood alcohol content (Lamond and Dawson, 1999).

LENGTH OF PRIOR WAKEFULNESS

The Length of Prior Wakefulness (LPW) score included most recent sleep loss, if any, and concomitant acute fatigue. Imagine the situation in which a person skips a night of sleep. *FAST*™ (Appendix B) shows the resulting cognitive effectiveness prediction (Figure 1; red curve and vertical axis) as a function of hours of wakefulness (horizontal axis) after awakening at 0600h (6 AM) at the left end of the x axis. The predicted value[1] stays above

[1] This is a population mean. You should expect half of a group of people to perform worse, and half to perform better.

90% until the normal bedtime at 2200h (10 PM), 16 hours after waking. This level of cognitive effectiveness (above 90%) received a low Checkcard score of 1 because it is consistent with the performance of safety-sensitive jobs such as operating a vehicle, protecting public safety, making command and control decision, etc.

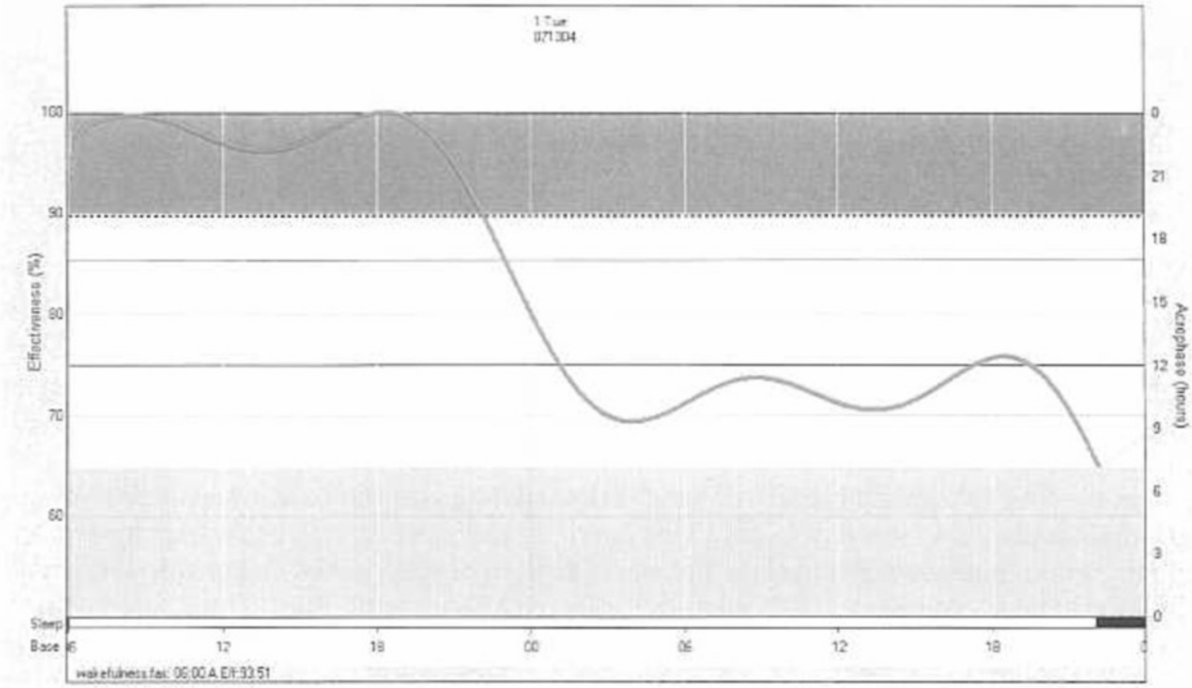


Figure 1. Cognitive effectiveness prediction (red curve and vertical axis) as a function of hours of continuous wakefulness after awakening at 0600h (6 AM) at the left end of the x axis (see Appendix B for further explanation of graph).

At 0100h, the prediction drops below 75%, entering that zone in which one suffers the pre-dawn malaise normally experienced while pulling an "all-nighter." The period from 2200-0100h (16 to 19 hours of continuous wakefulness) received a moderate score of 3. This is a level of cognitive effectiveness and a score consistent with the performance of non-safety-sensitive jobs. Once the prediction fell below 75%, the score became 5. This is a level of cognitive effectiveness and a score that is not consistent with the performance of any job. Thus, the revised scoring for this factor became:

Length of prior wakefulness (LPW)	**Score**
LPW < 16 h	1
16 <= 19 h	3
LPW > 19 h	5

These statements about job performance require a caveat. Most often, workers perform their jobs successfully and without mishaps when moderately or extremely fatigued. Similarly, drunk drivers usually drive without mishaps. The point in both cases is that the risk for mishap occurrence is sharply elevated to an unacceptable level. The goal of a fatigue countermeasures laboratory, such as ours, is to find ways to predict, reduce and otherwise manage the risk so that needed operations may continue without fatigue-induced mishaps. Conversely, in a mishap investigation the investigator must evaluate carefully the possibility that the risk of operating in a fatigued state has moved from the domain of theory into the real world, becoming a factor in the mishap.

AMOUNT OF PRIOR SLEEP FOR THE PRECEDING 72 H

The Amount of Prior Sleep (APS) score includes next-most recent sleep loss, if any, and concomitant cumulative fatigue. Imagine the situation in which a person acquires 8, 7, 6, 5 or even 4 hours of sleep per night for three successive nights preceding the day of the mishap. Sleep clinicians and scientists agree that the average sleep need is 8 hours per night[2]. For example, as I write this document the National Sleep Foundation's drowsy driving web site states:

> "Before hitting the road, drivers should:
> - Get a good night's sleep. While this varies from individual to individual, sleep experts recommend between 7-9 hours of sleep per night."

Sleep restriction (sleeping less than needed) causes cumulative fatigue. Up to a point, the brain acclimates to sleep restriction and the fatigued individual operates from day to day at a relatively stable level of cognitive effectiveness lower than the level represented by the 100% level in the SAFTE applied model. Beyond that point, homeostasis[3] is lost and cognitive performance declines from day to day. One metric of cognitive effectiveness impairment is the proportion of the day spent below a criterion level. For purposes of calculation for this Checkcard factor, we selected 90% cognitive effectiveness as a criterion. Three successive nights of 8 hours of sleep keeps the average individual above 90% cognitive effectiveness during all waking hours. Three successive nights of 7 hours of sleep keeps the average individual above 90% cognitive effectiveness during all but 6.5% of waking hours. These two amounts of sleep were assigned a low score of 1 on the Checkcard, indicating sufficient sleep. Three successive nights of 6 hours of sleep keeps the average individual above 90% cognitive effectiveness during about 86% of waking hours (Figure 2). On the Checkcard, this amount of sleep was assigned a moderate score of 3. Three successive nights of 5 hours of sleep leads to a loss of homeostasis, with only about half of one's waking hours spent above 90% cognitive effectiveness (Figure 3). This amount of sleep was assigned a score of 5 on the Checkcard. Thus, the revised scoring for this Checkcard factor became:

Amount of prior sleep for the preceding 72 h (APS)	**Score**
APS >= 21 hours	1
18 <= 21 hours	3
APS < 18 hours	5

---

[2] Actually, time in bed. For example, one gets about 7.5 hours of sleep during 8 hours in bed.

[3] The ability to self-regulate physiologically.

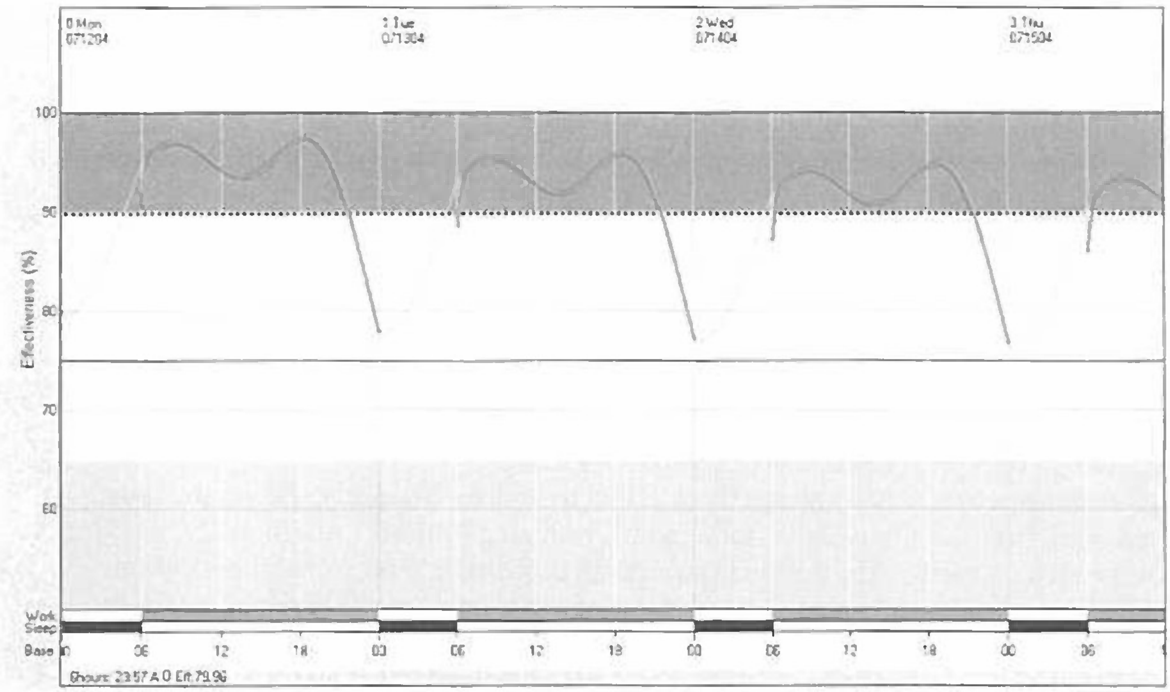


Figure 2. Three successive nights of 6 hours of sleep (blue bars on horizontal axis) keeps the average individual above 90% cognitive effectiveness during about 86% of waking hours (red bars) across the 72 hours. Cognitive effectiveness declines slowly from day to day.

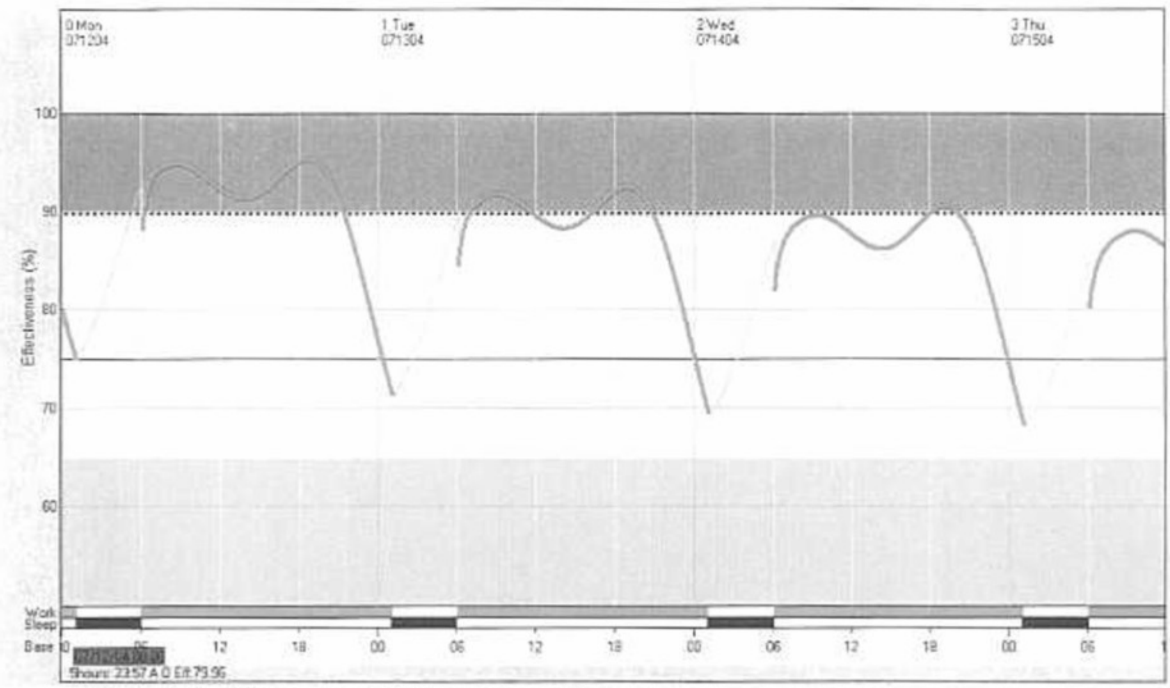


Figure 3. Three successive nights of 5 hours of sleep (blue bars on horizontal axis) keeps the average individual above 90% cognitive effectiveness during only about half of waking hours (red bars) across the 72 hours. Cognitive effectiveness declines rapidly from day to day.

TIME OF DAY/NIGHT OF THE MISHAP

The Time of Day/Night (TOD) score captured circadian rhythm effects. Again, imagine the situation in which a person skips a night of sleep and refer back to Figure 1. The predicted value stayed above 90% until the normal bedtime at 2200h. This prediction received a low score of 1. At 0100h, the prediction dropped below 75%. The period from 2200-0100h (16 to 19 hours) received a moderate score of 3. Once the prediction fell below 75%, the score became 5. Thus, the revised scoring for this factor became:

Time of day/night of the mishap (TOD)	Score
0600 < TOD <= 2200h	1
2200 < TOD <= 0100h	3
0100 < TOD <= 0600h	5

ACCLIMATION TO NIGHT WORK (SHIFT LAG)

Imagine that a person usually sleeps from 2200h to 0600h. Suddenly, the person must instead work from 2200h to 0600h for a month with no nights off. Additionally, imagine the best-case sleep scenario: the person is successful at sleeping after work from 0700h to 1500h[4]. The worker's circadian rhythms must now acclimate to the inverted work-rest cycle[5]. This takes a number of days as shown, in part, in Figure 4. Figure 4 shows two aspects of cognitive effectiveness during the 8-hour nocturnal work period: the average predicted cognitive effectiveness for the 8 hours and the proportion of the 8 hours during which the predicted cognitive effectiveness would be below 90%.

In Figure 4, we see that half of the work period is spent below 90% cognitive effectiveness until the 13th sequential night shift (magenta line). Also, the average predicted cognitive effectiveness for the work period stays below 90% until the 15th sequential night shift (black line). Thus, we can say that it takes at least 15 night shifts before a night worker may[6] have a high enough level of cognitive effectiveness to perform a safety-sensitive job. This latter situation (after 15 days) received a score of 1.

At the 8th sequential night shift, the worker achieves about 80% average cognitive effectiveness for the 8-hour work period and spends at least 25% of the work period above 90% cognitive effectiveness. This situation received a score of 3. The situation in which the worker has had fewer than 8 night shifts in which to acclimate to night work received a score of 5. Thus, the scoring for this Number of Night Shifts (NNS) factor became:

Number of night shifts in preceding 30 days (NNS)	Score
NNS >= 15	1
8 <= NNS <= 14	3
NNS < 8	5

[4] Most people need pharmacological sleep aids to sleep this well during the day.

[5] In fact, without aggressive attention to sleep hygiene and the sleep environment, very few workers' circadian rhythms acclimate fully to a day-sleep—night-work schedule.

[6] Quite often, rotating shift workers never achieve this level of cognitive effectiveness during night work.

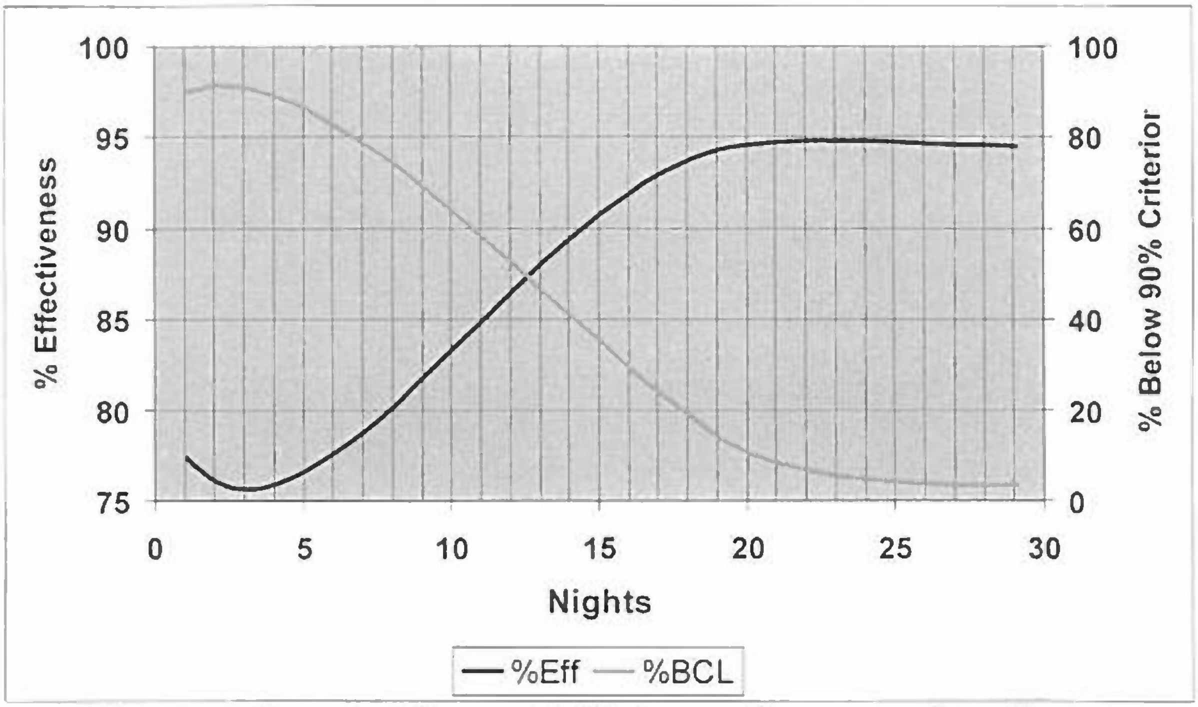


Figure 4. Effects of a 12-hour work shift change. Two aspects of cognitive effectiveness during the 8-hour nocturnal work period: the average predicted cognitive effectiveness for the 8 hours (%Eff, left axis, black line) and the proportion of the 8 hours during which the predicted cognitive effectiveness would be below 90% (%BCL, right axis, magenta line).

RE-ACCLIMATION TO DAY WORK (SHIFT LAG)

Though the pattern of change in cognitive effectiveness is somewhat different for the re-acclimation to day work from night work, compared to the original acclimation to night work, the time course of the change is about the same. Thus, for the well-acclimated night worker who makes a change to day work, the same scores may be used as for the acclimation to night work. Change the description of the factor to "Number of day shifts in preceding 30 days" and document the previous acclimation to night work.

ACCLIMATION TO A NEW TIME ZONE (JET LAG)

A rapid change[7] of time zones requires acclimation that is similar to a change to night work. The main difference is the presence of the powerful daylight-darkness cue that usually helps the traveler acclimate to the new time zone. Conversely, this cue usually impedes the night worker's ability to acclimate.

Imagine that a person has been shifted 12 time zones in one day[8] and that the person's circadian rhythms then "chase" the new local time by getting slightly later each day (a phase delay of the body clock, as in westward travel). Also, imagine that the traveler, immediately upon arrival in the destination time zone, takes up a new local work period of 0800h to 1600h and a successful, new local sleep period of 2200h to 0600h. *FAST*™ predicts that, for phase

[7] Faster than 1 time zone per day.
[8] From 90 degrees West to 90 degrees East longitude at the equator.

delay, the person's circadian rhythm will change at a rate of 1 hour per day for days 2 through 14 and then level off at the new alignment with the local time zone (Figure 5).

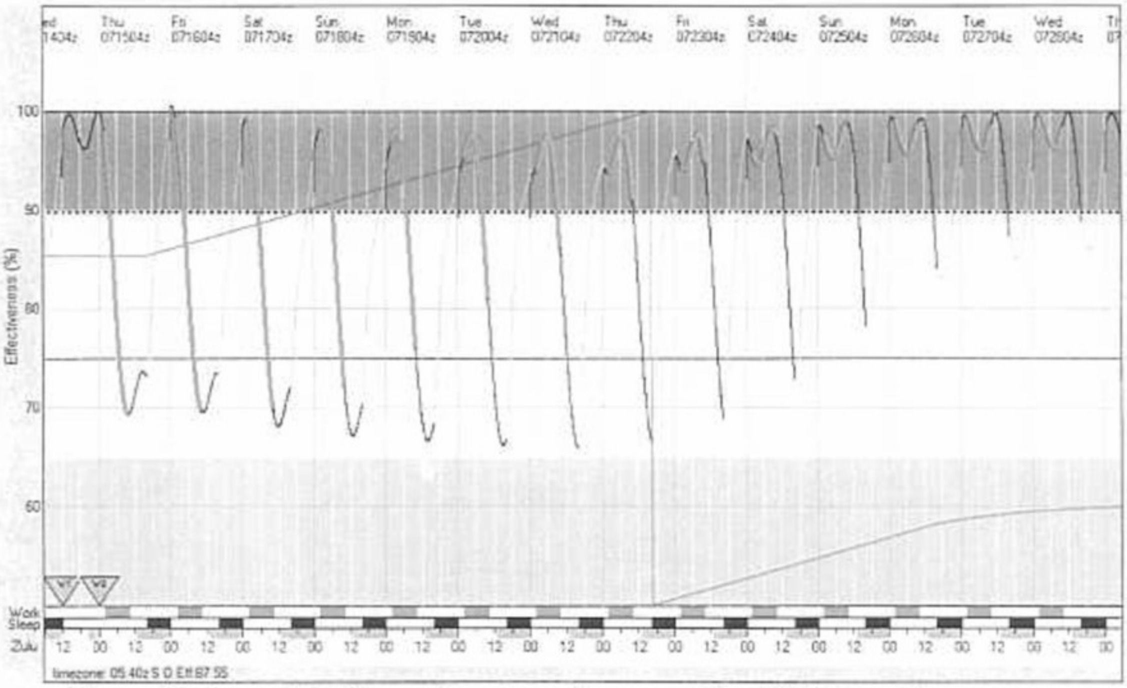


Figure 5. A rapid, 12-hour time zone change on Day 0, followed by acclimation to the new time zone. The thin red line, referenced to the right-hand vertical axis, shows the process of re-alignment of the circadian rhythm with the new time zone.

As in Figure 4, Figure 6 shows the average predicted cognitive effectiveness for the 8 daily work hours and the proportion of the 8 daily work hours during which the predicted cognitive effectiveness would be below 90%, in response to the 12-hour time zone shift.

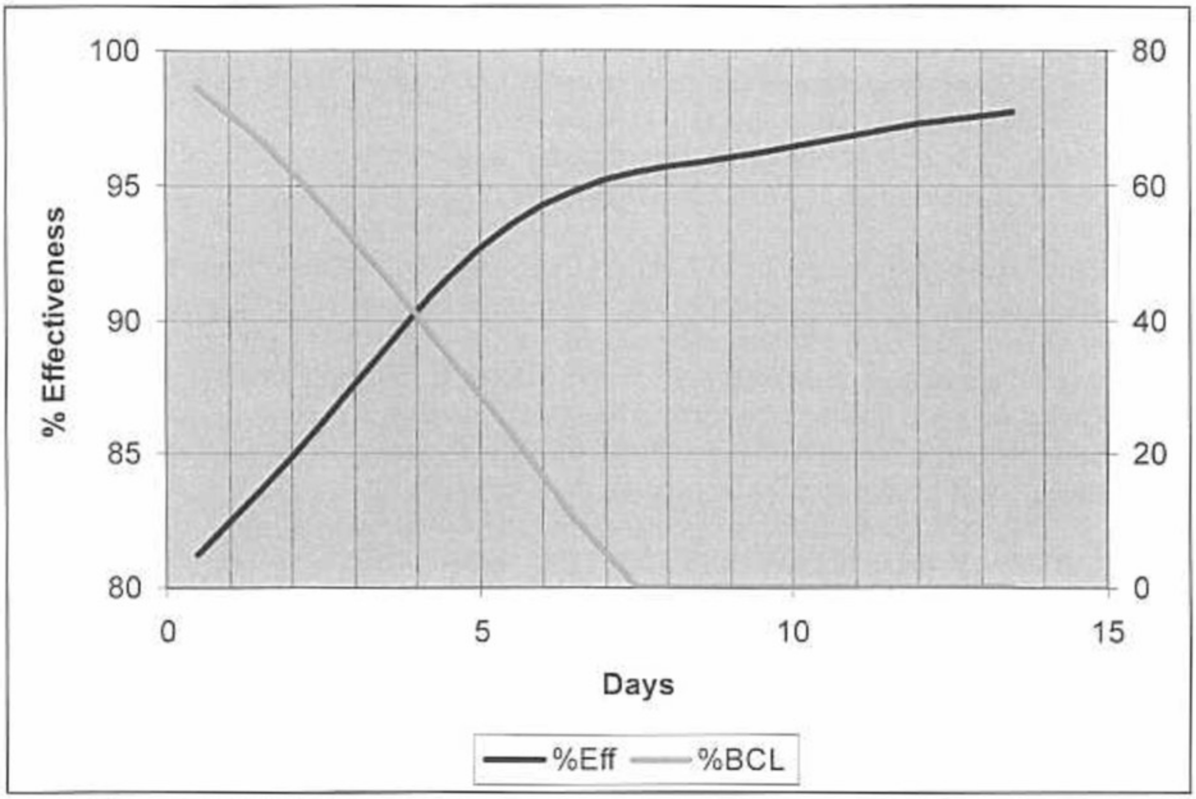


Figure 6. Effects of a 12-hour time zone shift. The average predicted cognitive effectiveness for the 8 daily work hours (%Eff, left axis, black line) and the proportion of the 8 daily work hours during which the predicted cognitive effectiveness would be below 90% (%BCL, right axis, magenta line).

In Figure 6, we see that half of the work period is spent below 90% cognitive effectiveness until the 4th day. Average predicted cognitive effectiveness for the work period stays below 90% until the 4th day. Thus, we can say that it takes at least 4 days on the new time zone before a worker may have a high enough level of cognitive effectiveness to perform a safety-sensitive job. This latter situation (after 4 days) received a score of 1.

After the 1st day in the new time zone, the worker achieves over 80% average cognitive effectiveness for the 8-hour work period and spends well over 25% of the work period above 90% cognitive effectiveness. This situation received a score of 3. The situation in which the worker has less than 1 day in which to acclimate to the new time zone received a score of 5.

Since the steep portions of the acclimation curves in Figure 6 were relatively rectilinear, an assumption of direct proportionality was applied to the acclimation period required for smaller time zone shifts than the 12 hours used in Figure 6. Dividing the number of time zones by 3 gives the number of days needed to reach a fatigue score of 1 for acclimation: 4 days for a 12-hour time zone change, 3 days for a 9-hour change, 2 days for a 6-hour change, and 1 day for a 3-hour change. Similarly, dividing the number of time zones by 12 gives the number of days needed to reach a fatigue score of 3 for acclimation: 1 day for a 12-hour change, ¾ day for a 9-hour change, ½ day for a 6-hour change, and ¼ day for a 3-hour change. In practice, the 1-day requirement may be applied only for time zone changes of 6 or more hours. Thus, the scoring for this Time Zone factor became:

Time zone change and days in zone	Score
[Any time change (hours) / Days in zone] < 3	1
Time change of 6 to 12 hours <u>and</u> days in zone > 1	3
Time change of 6 to 12 hours <u>and</u> days in zone <= 1	5

The calculation works for changes up to 12 hours (half-way around the world). For changes greater than 12 hours, subtract the change from 24 hours and use the remainder in the calculation. For example, a 14-hour change becomes a (24 – 14 =) 10 hour change. Actually, the human may be somewhat asymmetrical in the acclimation process: phase delay instead of phase advance may occur after rapid eastward travel of more than 10 time zones. However, this phenomenon has a relatively small effect with respect to the scoring used here and thus was ignored for the purpose of creating the Checkcard.

IMMEDIATE DAY WORK IN A DISTANT TIME ZONE

A rapid change of about 9 to 12 hours east or west shifts an individual naturally and quickly from a day worker into a night worker or vice versa. If this biological phenomenon has been exploited after the time zone change, then one need only score the fatigue effects of the time zone change. However, in most cases, a translocated day worker must try to acclimate quickly to day work in the new time zone. Assume in this case that the effects of the time zone change and shift change are additive.

TYPES OF HUMAN ERRORS ASSOCIATED WITH MISHAP

The Types of Human Error scoring guideline is based solely upon expert opinion and remains unchanged from the original:

Types of human errors associated with mishap	Score
Injured; impeded by poor interface design	1
Distraction	2
Poor planning; bad decision	3
Slow reaction time	4
Fell asleep; dozed off	5

PHYSICAL FATIGUE

There is no known quantitative relationship between cognitive fatigue and physical fatigue. However, it is known that a high level of exercise (a score of 4 or 5) within 3 or 4 hours of bedtime may disturb sleep, especially for those who do not exercise regularly. Also, there are reports that sleep quality may be improved when aerobic fitness is increased. We were not able to create a score that relates physical fatigue to cognitive fatigue. Thus, we deal here only with physical fatigue as it may have existed at the time of the mishap.

The scores for this factor were derived from the perceived exertion scale devised by Borg. The 15-point scale used here was one variant of a scale designed to allow estimates of heart rate caused by varying levels of dynamic physical work (Borg, 1985; Kilbom, 1991). The scale was anchored with a statement at about every other number, and provided a rough estimate (rating x 10) of heart rate for a young, fit male. The user of the scale reported the number that was his/her best estimate across the work period:

6. No exertion at all
7.
7.5 Extremely light
8.
9. Very light
10.
11. Light
12.
13. Somewhat hard
14.
15. Hard (heavy)
16.
17. Very hard
18.
19. Extremely hard
20. Maximal exertion

For the Checkcard, the Physical Fatigue scale was degraded to 5 levels:

Estimated exertion across the work period of interest	Score
No exertion at all or extremely light	1
Very light or light	2
Somewhat hard or hard (heavy)	3
Very hard	4
Extremely hard or maximal exertion	5

INVESTIGATION PROTOCOL

The revised Fatigue Checkcard is made up of seven scored factors, as follows (a reproducible Checkcard is shown in Appendix D):

A. Length of Prior Wakefulness (LPW)	**Rating**
LPW <= 16 hrs	1
16 <= LPW < 19 hrs	3
LPW > 19 hrs	5
B. Amount of Prior Sleep for the Preceding 72 h (APS)	
APS >= 21 hrs	1
18 <= APS < 21 hrs	3
APS < 18 hrs	5
C. Time of Mishap (TOD)	
0600 < TOD <= 2200h	1
2200 < TOD <= 0100h	3
0100 < TOD <= 0600h	5
D. Number of Night Shifts in Preceding 30 Days (NNS)	
NNS >= 15	1
8 <= NNS <= 14	3
NNS < 8	5
E. Time Zone Change and Days in Zone	
[Any time change (hours) / Days in zone] < 3	1
Time change of 6 to 12 hours <u>and</u> days in zone > 1	3
Time change of 6 to 12 hours <u>and</u> days in zone <= 1	5
F. Types of Human Errors Associated with Mishap	
Injured; impeded by poor interface design	1
Distraction	2
Poor planning; bad decision	3
Slow reaction time	4
Fell asleep; dozed off	5
G. Estimated Exertion Across the Work Period of Interest	
No exertion at all or extremely light	1
Very light or light	2
Somewhat hard or hard (heavy)	3
Very hard	4
Extremely hard or maximal exertion	5

The notes associated with these factors and scores include the following:

Investigators should use their judgment to provide interpolated scores of 2 and 4, as needed, for Factors A through E and to adjust other scores from these guidelines. However, the reasoning for interpolations and adjustments should be documented.

Factor A, the length of prior wakefulness, refers to the continuous period of wakefulness leading up to the mishap. Thus, if the mishap occurred three hours after the person awoke from a night of sleep, the amount would be three hours and the score would be 1. If the mishap occurred 20 hours after the last nocturnal sleep period, then the amount would be 20 hours and the score would be 5. The investigator has some leeway determining the last "good quality" sleep period from which to start counting. Generally, nocturnal sleep is better than daytime sleep for recovery from fatigue.

Factor B, amount of prior sleep for the preceding 72 hours, refers to the total amount of "good quality" sleep acquired in that period. Again, the investigator has some leeway in determining the occurrence of "good quality" sleep. Generally, nocturnal sleep is better than daytime naps. Factor C, time of day/night of the mishap, should be self-explanatory.

For Factor D, number of preceding night shifts in preceding 30 days, a higher score means that the worker has had fewer nights to acclimate to night work. If on days off between night shifts the worker reverted to a day waking and night sleeping pattern, then increase the score by 1 or more.

For the well-acclimated night worker who makes a change to day work, the same scores may be used as for the acclimation to night work. Change the description of the factor to "Number of preceding day shifts in 30 days" and document the immediately preceding acclimation to night work.

Similarly, for Factor E, time zone change (in hours), a higher score means that the worker has had fewer days to acclimate to the new time zone. The calculation works for changes up to 12 hours (half-way around the globe). For changes greater than 12 hours, subtract the change from 24 hours and use the remainder in the calculation. For example, a 14-hour change becomes a (24 – 14 =) 10 hour change.

For immediate <u>night</u> work in a distant time zone after a rapid change of 9 to 12 hours east or west by a day worker, score only the fatigue effects of the time zone change. For immediate <u>day</u> work in a distant time zone after a rapid change of 9 to 12 hours east or west by a day worker, assume that the effects of the time zone change and shift change are additive. The converse is somewhat true, also, for a night worker that moves rapidly across time zones. However, note that the night worker is highly likely to be fatigued before the time zone change and increase the score accordingly.

For Factors D and E, it is unlikely that one individual will be involved in both shiftwork and time zone transitions at the same time. Thus it is likely that, if Factor D is scored then Factor E will not be scored and *vice versa.*

For Factor F, types of human errors associated with mishap, use the highest score among all types of human errors thought by investigators to contribute to the mishap. Factor G, estimated exertion across the work period of interest, allows the investigator to account for physical fatigue as it may have existed at the time of the mishap.

To assign a score to a mishap, collect all data relevant to the Checkcard factors to the extent possible. The data sources will be best estimates by mishap personnel, by colleagues and family of mishap personnel and by the investigators. All data sources should be documented in support of the final fatigue score. If any single factor's score is a 5, or if the sum of the seven ratings is 21 or higher, or if the average score (sum / 7) is greater than 3, then fatigue may have been a factor in the mishap. If, based upon the Checkcard score, fatigue may have been a factor, then contact a fatigue expert for additional help in the investigation. The expert should confirm or negate the tentative, Checkcard-based finding that fatigue may have been a factor.

REFERENCES

Borg G (1985). *An Introduction to Borg's RPE-Scale.* Ithaca NY, Movement Publications.

Dawson D, Reid K (1997). Fatigue, alcohol and performance impairment. *Nature* 388: 235, 17 July.

Hursh SR, Redmond DP, Johnson ML, Thorne DR, Belenky G, Balkin TJ, Storm WF, Miller JC, Eddy DR. (2004). Fatigue models for applied research in warfighting. *Aviation, Space and Environmental Medicine*, 75(3), Section II, Supplement, pp. A44-A53.

Kilbom A (1991). Measurement and assessment of dynamic work. Ch. 22 in JR Wilson and EN Corlett (ed.), *Evaluation of Human Work*, London, Taylor & Francis.

Lamond N, Dawson D (1999). Quantifying the performance impairment associated with fatigue. *Journal of Sleep Research* 8(4): 255-262.

Neri DF (ed.) (2004). Proceedings of the Fatigue and Performance Modeling Workshop, June 2002. *Aviation, Space and Environmental Medicine*, 75(3), Section II, Supplement.

APPENDIX A
Fatigue Basics

In any human-machine system, the most variable (unpredictable) component in the system is the human. After training and currency, the greatest contributor to that variability is fatigue.

Good human-machine system design exploits human strengths and protects the system from human weaknesses. This is a fundamental concept in human factors engineering. The human brings to a system much more powerful pattern recognition capabilities and decision-making skills than can be provided in software. However, the human also brings much more performance variability to a system than one finds in software and modern hardware.

Training and currency are sources of human variability. When novices are learning to operate a complex system, they display a learning curve. Initially, their performance is quite poor and variable, but they learn the basics quickly. Next, their performance is better, on average, but still more variable than desired. Finally, as they approach the expert user level, their average performance is quite good and it varies only a small amount. Similarly, when an expert user becomes "rusty" in the operation of a complex system, their performance may be more variable than desired until they return to their expert level.

One of the primary hallmarks of human fatigue is performance variability. This is due to large amplitude, moment-to-moment fluctuations in attentiveness associated with fatigue. Average performance may be acceptable, but there are brief periods when responses are extraordinarily delayed or absent ("lapses"). We often call this "distractibility."

For purposes of study, we sort the generators of fatigue into the four categories *circadian*[9], acute, cumulative, and chronic. There are inherent, unavoidable, 24-hour rhythms in human cognitive and physical performance. Most of these circadian rhythms oscillate between their high point late in the day to their low point in the pre-dawn hours with a peak-to-trough amplitude of about 5 to 10% of their average. Acute fatigue builds up unavoidably within in one waking and duty period, but recovery from acute fatigue occurs as the result of one good-quality, nocturnal sleep period. Cumulative fatigue builds up across major waking and duty periods because there is inadequate recovery (due to inadequate sleep) between the duty periods. Recovery from cumulative fatigue cannot be accomplished in one good-quality, nocturnal sleep period.

Chronic fatigue may set in after one to two weeks of cumulative fatigue. Its symptoms[10] are similar to those of Chronic Fatigue Syndrome (CFS). However, unlike CFS, the cause is known (continuing cumulative fatigue) and it occurs much sooner than the 6-month diagnostic requirement for CFS. The Air Force Safety Center has in the past called chronic fatigue "motivational exhaustion." While this label accounts for only one of several possible

---

[9] From the Latin *circa*, about, and *dia*, day: A cycle length of about one day.

[10] The desire to sleep, apathy, substantial impairment in short-term memory or concentration; muscle pain; multi-joint pain without swelling or redness; headaches of a new type, pattern or severity; unrefreshing sleep; and post-exertional malaise lasting more than 24 hours.

symptoms of chronic fatigue (apathy), it describes well the attitude that one observes in a person with chronic fatigue.

Fatigue is ubiquitous, pervasive and insidious. By ubiquitous we mean that fatigue affects everybody. There are individual differences: a few people are truly more resistant to fatigue effects than others. Most people seem to feel, without basis, that they are more resistant to fatigue effects than others. This misperception can lead to the formation of ill-advised intentions.

By pervasive, we mean that fatigue affects everything we do, physically and cognitively. Again, there are individual differences. In the physical domain, there are those who are inherently able to train to much greater levels of strength and endurance than the rest of us. This may also be true in the domains of cognition and attention.

By insidious, we mean that often when we are fatigued, we are quite unaware of how badly we are performing. Most people have experienced the attention lapse associated with mild fatigue when they miss a freeway exit or realize suddenly that they don't remember the last mile or two driven on the highway. Similarly, most people recovering from a period of physical, emotional or cognitive stress have uttered the phrase, "I did not realize how tired I was!"

Fortunately, the biological changes and rhythms that cause fatigue-induced variability in human performance are relatively lawful and predictable. We have quantitative models and simulations, implemented in software, that allow us to estimate and predict the timing and severity of fatigue episodes, given some information about when and how much people sleep. The quantitative approach is combined here with expert opinion to provide a screening tool for mishap investigators.

Appendix B
The Sleep, Activity, Fatigue and Task Effectiveness (SAFTE) Applied Model and the Fatigue Avoidance Scheduling Tool (*FAST*™)

The Sleep, Activity, Fatigue and Task Effectiveness (SAFTE) applied model integrates quantitative information about (1) circadian rhythms in metabolic rate, (2) cognitive performance recovery rates associated with sleep, and cognitive performance decay rates associated with wakefulness, and (3) cognitive performance effects associated with sleep inertia to produce a 3-process model of human cognitive effectiveness.

- The SAFTE applied model has been under development by Dr. Steven Hursh for more than a decade. Dr. Hursh, formerly a research scientist with the Army, is employed by SAIC and Johns Hopkins University and is currently under contract to the WFC R&D Group and NTI, Inc. to modify and expand the model.
- The general architecture of the SAFTE applied model is shown in Figure 1. A circadian process influences both cognitive effectiveness and sleep regulation. Sleep regulation is dependent upon hours of sleep, hours of wakefulness, current sleep debt, the circadian process and sleep fragmentation (awakenings during a sleep period). Cognitive effectiveness is dependent upon the current balance of the sleep regulation process, the circadian process, and sleep inertia.

Schematic of SAFTE Model

Sleep, Activity, Fatigue and Task Effectiveness Model

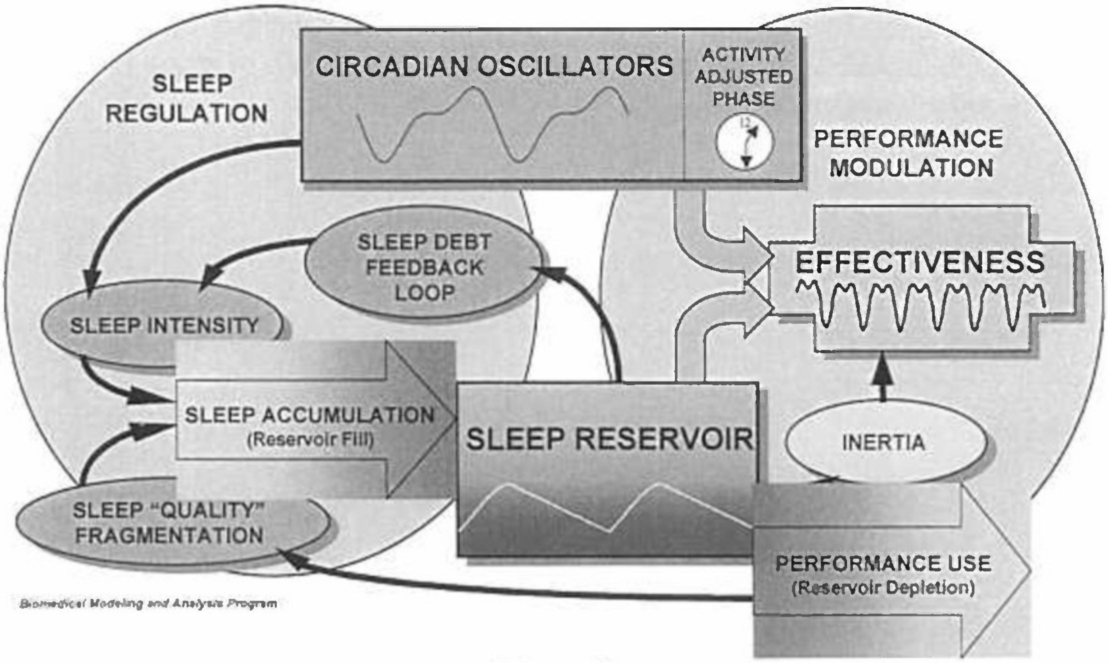


Figure 1.

- SAFTE has been validated against group mean data from a Canadian laboratory that were not used in the model's development (Hursh et al., in review). Additional laboratory and field validation studies are underway and the model has begun the USAF Verification, Validation and Accreditation (VV&A) process.

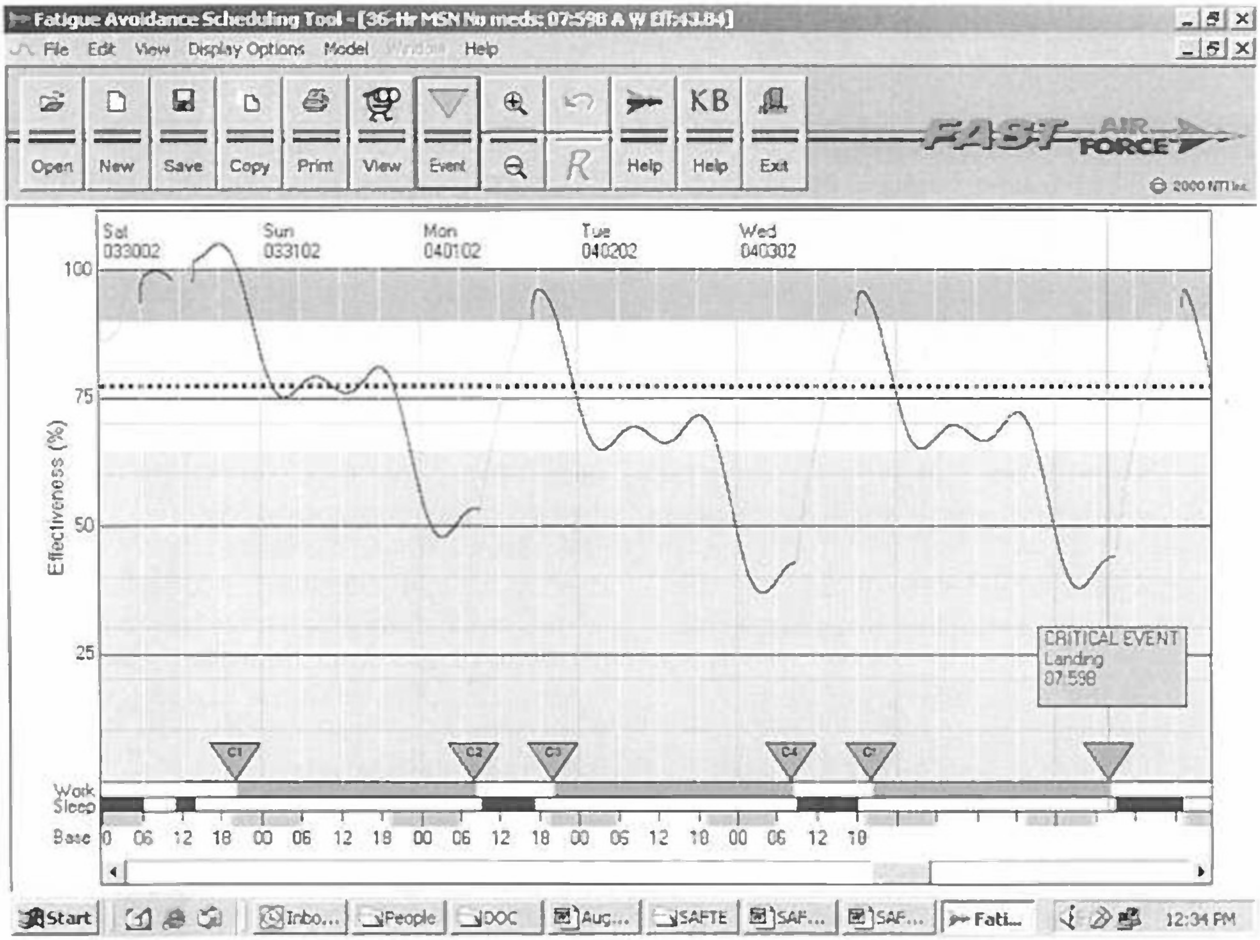
- The applied model does not incorporate the effects of pharmacological alertness aids; chronic fatigue; chronic fatigue syndrome; fatiguing physiological factors such as exercise, hypoxia or acceleration; sleep disorders; or the fatiguing effects of infection.

The SAFTE applied model has a number of essential features that distinguish it from other attempts to model sleep and fatigue (Table 1). Together, these features of the model allow it to make very accurate predictions of performance under a variety of work schedules and levels of sleep deprivation.

Table 1. SAFTE applied model essential features.

Key Features	**Advantages**
Model is homeostatic. Gradual decreases in sleep debt decrease sleep intensity.	Predicts the normal decline in sleep intensity during the sleep period.
Progressive increases in sleep debt produced by extended periods of less than optimal levels of sleep lead to increased sleep intensity.	Predicts the normal equilibrium of performance under less than optimal schedules of sleep.
Model delays sleep accumulation at the start of each sleep period.	Predicts the detrimental effects of sleep fragmentation and multiple interruptions in sleep.
Model incorporates a multi-oscillator circadian process.	Predicts the asymmetrical cycle of performance around the clock.
Circadian process and Sleep-Wake Cycle are additive to predict variations in performance.	Predicts the mid-afternoon dip in performance, as well as the more predominant nadir in performance that occurs in the early morning.
Model modulates the intensity of sleep according to the time of day.	Predicts circadian variations in sleep quality. Predicts limits on performance under schedules that arrange daytime sleep.
Model includes a factor to account for the initial lag in performance upon awakening.	Predicts sleep inertia that is proportional to sleep debt.
Model incorporates adjustment to new time zones or shift schedules	Predicts temporary "jet lag" effects and adjustment to shift work

The Fatigue Avoidance Scheduling Tool (*FAST*™) is based upon the SAFTE applied model. *FAST*™, developed by NTI, Inc. as an AF SBIR product, is a Windows® program that allows planners and schedulers to estimate the average effects of various schedules on human performance. It allows work and sleep data entry in graphic and text formats. A work schedule comprised of three 36-hr missions each separated by 12 hours is shown as red bands on the time line across the bottom of the graphic presentation format in Figure 2. Average performance effectiveness for work periods may be extracted and printed as shown in the table below the figure.



36-Hr MSN No meds -- 03/30/2002

Awake			Work		
Start Day - Hr	Duration (Minutes)	Mean Effectiveness	Start Day - Hr	Duration (Minutes)	Mean Effectiveness
0 - 06:00	300	98.97	0 - 20:00	1079	81.14
0 - 14:00	2580	76.42	1 - 14:00	1080	63.97
2 - 17:00	2400	64.78	2 - 20:00	1079	71.23
4 - 18:00	2340	64.58	3 - 14:00	1080	54.51
6 - 19:00	1741	72.23	4 - 20:00	1079	72.00
			5 - 14:00	1080	54.92

Figure 2. Sample *FAST*™ display. The triangles represent waypoint changes that control the amount of light available at awakening and during various phases of the circadian rhythm. The table shows the mission split into two work intervals, first half and second half.

- Sleep periods are shown as blue bands across the time line, below the red bands.
- The vertical axis of the diagram represents composite human performance on a number of associated cognitive tasks. The axis is scaled from zero to 100%. The oscillating line in the diagram represents expected group average performance on these tasks as determined by time of day, biological rhythms, time spent awake, and amount of sleep. We would expect the predicted performance of half of the people in a group to fall below this line.
- The green area on the chart ends at the time for normal sleep, ~90% effectiveness.
- The yellow indicates caution.
- The area from the dotted line to the red area represents performance level during the nadir and during a 2nd day without sleep.
- The red area represents performance effectiveness after 2 days and a night of sleep deprivation.

The expected level of performance effectiveness is based upon the detailed analysis of data from participants engaged in the performance of cognitive tasks during several sleep deprivation studies conducted by the Army, Air Force and Canadian researchers. The algorithm that creates the predictions has been under development for two decades and represents the most advanced information available at this time.

References

Eddy DR, Hursh SR (2001). *Fatigue Avoidance Scheduling Tool (FAST).* AFRL-HE-BR-TR-2001-0140, SBIR Phase I Final Report, Human Effectiveness Directorate Biodynamics and Protection Division, Flight Motion Effects Branch, Brooks AFB TX 78235-5105.

Hursh SR, Redmond DP, Johnson ML, Thorne DR, Belenky G, Balkin TJ, Storm WF, Miller JC, Eddy DR. (2004). Fatigue models for applied research in warfighting. *Aviation, Space and Environmental Medicine*, 75(3), Section II, Supplement.

Hursh SR (1998). *Modeling Sleep and Performance within the Integrated Unit Simulation System (IUSS).* Technical Report Natick/TR-98/026L. Science and Technology Directorate, Natick Research, Development and Engineering Center, United States Army Soldier Systems Command, Natick, Massachusetts 01760-5020.

APPENDIX C. Original Checkcard

FATIGUE FACTOR RATINGS FOR MISHAPS

A. Length of prior wakefulness	Rating
<= 4 h	1
4 <= 8 h	2
8 <= 16 h	3
16 <= 24 h	4
> 24 h	5
B. Amount of prior sleep for the preceding 72 h	
> 24 h	1
21 <= 24 h	2
18 <= 21 h	3
15 <= 18 h	4
<= 15 h	5
C. Time of day/night of the mishap	
07 <=14, 17 <= 23	1
23 <= 00	2
06 <= 07, 00 <= 02	3
14 <= 17	4
02 <= 06	5
D. Time zone crossings in the preceding 14 days	
0 zones	1
1 < 2 zones	2
3 <= 6 zones	3
7 <= 8 zones	4
9 <=12 zones	5
E. Types of human errors associated with mishap	
Injured; impeded by poor interface design	1
Distraction	2
Poor planning; bad decision	3
Slow reaction time	4
Fell asleep; dozed off	5
SUM	

If any single factor is a **5**, or if the sum of the five ratings is **15** or higher, then fatigue was likely to have been a factor in the mishap.

5 Mar 2003

APPENDIX D. Revised Checkcard
(next two pages)

AFRL FATIGUE CHECKCARD FOR MISHAP INVESTIGATIONS

A. Length of Prior Wakefulness (LPW)	**Rating**
LPW <= 16 hrs	1
16 <= LPW < 19 hrs	3
LPW > 19 hrs	5
B. Amount of Prior Sleep for the Preceding 72 h (APS)	
APS >= 21 hrs	1
18 <= APS < 21 hrs	3
APS < 18 hrs	5
C. Time of Mishap (TOD)	
0600 < TOD <= 2200h	1
2200 < TOD <= 0100h	3
0100 < TOD <= 0600h	5
D. Number of Night Shifts in Preceding 30 Days (NNS)	
NNS >= 15	1
8 <= NNS <= 14	3
NNS < 8	5
E. Time Zone Change and Days in Zone	
[Any time change (hours) / Days in zone] < 3	1
Time change of 6 to 12 hours <u>and</u> days in zone > 1	3
Time change of 6 to 12 hours <u>and</u> days in zone <= 1	5
F. Types of Human Errors Associated with Mishap	
Injured; impeded by poor interface design	1
Distraction	2
Poor planning; bad decision	3
Slow reaction time	4
Fell asleep; dozed off	5
G. Estimated Exertion Across the Work Period of Interest	
No exertion at all or extremely light	1
Very light or light	2
Somewhat hard or hard (heavy)	3
Very hard	4
Extremely hard or maximal exertion	5
SUM	

AFRL/HEPF
October 2004

Fatigue Checkcard Notes:

- Use your judgment to provide interpolated scores of 2 and 4, as needed, for Factors A through E and to adjust other scores. Document your reasoning for interpolations and adjustments.
- **Factor A**, length of prior wakefulness, refers to the continuous period of wakefulness leading up to the mishap. Thus, if the mishap occurred three hours after the person awoke from a night of sleep, the amount would be three hours and the score would be 1. If the mishap occurred 20 hours after the last nocturnal sleep period, then the amount would be 20 hours and the score would be 5. You have some leeway in determining the last "good quality" sleep period from which to start counting. Generally, nocturnal sleep is better than daytime naps for recovery from fatigue. However, some people are good nappers who experience substantial recovery in naps. In this case, a daytime nap may be used as the last good sleep period.
- **Factor B**, amount of prior sleep for the preceding 72 hours, refers to the total amount of "good quality" sleep acquired in that period. Again, you have some leeway in determining the occurrence of "good quality" sleep. Generally, nocturnal sleep is better than daytime sleep.
- **Factor C**, time of day/night of the mishap, should be self-explanatory.
- For **Factor D**, number of preceding night shifts in preceding 30 days, a higher score means that the worker has had fewer nights to acclimate to night work. If during days off between night shifts the worker reverted to a day waking and night sleeping pattern, then increase the score by 1 or more. For the well-acclimated night worker who makes a change to day work, the same scores may be used as those used for the acclimation to night work. Change the description of the factor to "Number of preceding day shifts in 30 days" and document the immediately preceding acclimation to night work.
- Similarly, for **Factor E**, time zone change (in hours), a higher score means that the worker has had fewer days to acclimate to the new time zone. The calculation works for changes up to 12 hours (half-way around the globe). For changes greater than 12 hours, subtract the change from 24 hours and use the remainder in the calculation. For example, a 14-hour change becomes a (24 – 14 =) 10 hour change.
- For immediate <u>night</u> work in a distant time zone after a rapid change of 9 to 12 hours east or west by a day worker, score only the fatigue effects of the time zone change. For immediate <u>day</u> work in a distant time zone after a rapid change of 9 to 12 hours east or west by a day worker, assume that the effects of the time zone change and shift change are additive. The converse is somewhat true, also, for a night worker that moves rapidly across time zones. However, note that the night worker is highly likely to be fatigued before the time zone change and increase the score accordingly.
- For Factors D and E, it is unlikely that one individual will be involved in both shiftwork and time zone transitions at the same time. Thus it is likely that, if Factor D is scored then Factor E will not be scored and vice versa.
- For **Factor F**, types of human errors associated with mishap, use the highest score among all types of human errors thought by investigators to contribute to the mishap.
- **Factor G**, estimated exertion across the work period of interest, accounts for physical fatigue as it may have existed at the time of the mishap.
- Collect and document all data relevant to the Checkcard factors to the extent possible. The data sources will be best estimates by mishap personnel, by colleagues and family of mishap personnel and by the investigators.

Fatigue Checkcard scoring: If any single factor's score is a 5, or if the sum of the seven ratings is 21 or higher, or if the average score (sum / 7) is greater than 3, then fatigue may have been a factor in the mishap.
Fatigue Checkcard use: If fatigue might have been a factor, then contact a fatigue expert for additional help in the investigation. The expert should confirm or negate the tentative, Checkcard-based finding.

AFRL/HEPF
October 2004